AG Contract No. KR00 1870TRN
ADOT ECS File: JPA 00-158
Project No. SPR-93
TRACS No.: R0493 12P
Research: Drilled Shaft Bridge Foundation Design and Procedures for Bearing in SGC Soils

INTERAGENCY AGREEMENT
BETWEEN
THE DEPARTMENT OF TRANSPORTATION
AND
THE ARIZONA STATE UNIVERSITY

THIS AGREEMENT is entered into 18 November, 2000, between agencies of the State of Arizona, to wit; the DEPARTMENT OF TRANSPORTATION (the "DOT") and the ARIZONA BOARD OF REGENTS, acting for and on behalf of ARIZONA STATE UNIVERSITY, (the "University").

I. RECITALS

1. The DOT is empowered by Arizona Revised Statutes Section 28-401 to enter into this agreement and has by resolution, a copy of which is attached hereto and made a part hereof, resolved to enter into this agreement and has delegated to the undersigned the authority to execute this agreement on behalf of the DOT.

2. The University is empowered by Arizona Revised Statutes Section 15-1626 to enter into this agreement and has delegated to the undersigned authority to execute this agreement on behalf of the University.

3. The DOT and the University desire to conduct research and develop design parameters and procedures for drilled shaft bridge foundations bearing in sand gravel cobbles ("SGC") soils, all in accordance with Exhibit A which is attached hereto and made a part hereof, at an estimated total cost of $150,000.00, all at DOT expense, hereinafter referred to as the Project.

THEREFORE, in consideration of the mutual agreements expressed herein, it is agreed as follows:

==

II. SCOPE OF WORK

1. The DOT will.

a. Appoint a Project coordinator within the DOT's Transportation Research Center to interface with the University relating to the research and development.

b. Provide the University with information and data as may be reasonably available to assist in the Project research and development. Review and approve monthly invoices, accompanied by research progress reports and summary of research project costs and expenditures

c. Reimburse the University within forty-five (45) days after receipt and approval of monthly invoices, in a total amount currently estimated at $150,000.00

2. The University will:

a. Appoint a Project coordinator at the University (ASU) to interface with the DOT relating to the research and development.

b. Accomplish the research and development generally in accordance with Exhibit A, which is attached hereto and made a part hereof, provide the DOT with appropriate progress reports, and a final report documenting the program, data derived, and the final results. Such reports will be in a format compliant with the DOTs "Guidelines for Preparing Research Reports."

c. No more often than monthly, invoice the DOT in the form of Exhibit B attached hereto, supported by narrative progress reports and an accounting of monthly costs and expenditures on the Project. Upon completion of the Project, provide the DOT with a detailed final report

III. MISCELLANEOUS PROVISIONS

1. Title to all documents, reports and other deliverables prepared by the University in performance of this agreement shall rest jointly with the DOT and the University

2. This agreement shall become effective upon signature by the parties hereto, and shall remain in force and effect until on or about 28 February 2002, or until completion of said Project and reimbursements; provided, however, that this agreement, may be cancelled at any time, upon thirty (30) days written notice to the other party

3. The parties agree to comply with all applicable state and federal laws, rules, regulations and executive orders governing equal employment opportunity, immigration, nondiscrimination and affirmative action.

4. This agreement may be cancelled in accordance with Arizona Revised Statutes Section 38-511.

5. The provisions of Arizona Revised Statutes Section 35-214 are applicable to this contract

6. In the event of any controversy which may arise out of this agreement, the parties hereto agree to abide by required arbitration as is set forth for public works contracts in Arizona Revised Statutes Section 12-1518.

7. All notices or demands upon any party to this agreement relating to the agreement shall be in writing and shall be delivered in person or sent by mail addressed as follows:

Department of Transportation Joint Project Administration 205 S. 17th Avenue - 616E Phoenix, AZ 85007	Arizona State University Del Webb School of Construction PO Box 870204 Tempe, AZ 85287-0204

8. The parties recognize that performance by ASU under this Agreement may be dependent upon the appropriation of funds by the State Legislature of Arizona. Should the Legislature at any time fail to appropriate the necessary funds for such performance, the, by written notice to the DOT, ASU may cancel this Agreement.

IN WITNESS WHEREOF, the parties have executed this agreement the day and year first above written.

STATE OF ARIZONA

THE ARIZONA BOARD OF REGENTS acting for and on behalf of ARIZONA STATE UNIVERSITY	**DEPARTMENT OF TRANSPORTATION**
By ______ GARY DELAGO, Director Office of Research and Creative Activities	By ______ MARY LYNN TISCHER, Director Transportation Planning Division
11 · 7 · 00 (date)	11/18/00 (date)

Proposal

SPR 493

Drilled Shaft Bridge Foundation Design Parameters and Procedures for Bearing in SGC Soils

July 13, 2000

Submitted to:

Arizona Department of Transportation

Mr. Frank McCullagh, Project Officer

Kenneth D. Walsh
Associate Professor
Del E. Webb School of Construction

William N. Houston
Professor
Department of Civil and Environmental Engineering

Sandra L. Houston
Professor & Chair
Department of Civil and Environmental Engineering

ARIZONA STATE UNIVERSITY

College of Engineering and Applied Sciences

Del E. Webb School of Construction
Department of Civil and Environmental Engineering
Main Campus
Box 870204
Tempe, AZ 85287-0204

Exhibit A to JPA 00-158

TABLE OF CONTENTS

IDENTIFICATION

SPR 493

Project Title: Drilled Shaft Bridge Foundation Design Parameters and Procedures for Bearing in SGC Soils

Proposing Agency:	Arizona Board of Regents acting on behalf of Arizona State University P.O. Box 871603 Tempe, Arizona 85287-1603
Person Submitting Proposal:	Janice D. Bennett, Director Office of Research and Creative Activities
Proposal Date:	July 11, 2000
Principal Investigator/ Project Manager:	Kenneth D. Walsh, Ph.D., P.E. Associate Professor Arizona State University P.O. Box 870204 Tempe, Arizona 85287-0204 Tel: (480) 965-0306 Fax: (480) 965-1769 E-mail: ken.walsh@asu.edu
Proposal Written by:	Kenneth D. Walsh, Ph.D., P.E. William N. Houston, Ph.D., P.E. Sandra L. Houston, Ph.D., P.E.
Administrative Officer:	Joseph Wessels, Sponsored Projects Officer Office of Research and Creative Activities Arizona State University P.O. Box 871603 Tempe, Arizona 85287-1603 Tel: (480) 965-1427 Fax: (480) 727-6285
Proposed Contract Period:	18 months (9/1/00 – 2/28/02)

Problem Statement, Background, and Significance of Work

Drilled shaft foundations are extensively used in transportation applications in the state of Arizona. Because soil conditions are generally unfavorable to driven pile elements, because scour depths on the ephemeral river channels are frequently quite large, and because of the increased confidence in the identification of the bearing layer afforded by the drilled shaft construction process, drilled shafts have in fact become the preferred deep foundation element in the State. The design of these foundation elements is conducted in accordance with local experience and the guidance of the relevant AASHTO design methods for drilled shaft foundations, contained in Section 4.6.5 of the AASHTO Standard Specifications for Highway Bridges. Seventeenth Edition 1996.

The AASHTO standard proposes a limit equilibrium design method, in which the ultimate capacity of the deep foundation is divided into a tip bearing component and a skin friction component,

$$Q_{ult} = Q_s + Q_t - W \qquad \text{Equation (1)}$$

Where: Q_{ult}= the ultimate axial capacity of a foundation element
Q_s= the ultimate side resistance or skin friction
Q_t= the ultimate tip resistance
W= the weight of the foundation element.

All of these variables are used in force units. To obtain the allowable capacity, the ultimate capacity calculated above is divided by a factor of safety. Factors of safety of 2.0 to 2.5 are expressed in the standard (Section 4.6.5.4) depending on the degree of field quality control which will be exercised. It is common practice in Arizona to apply separate factors of safety to the skin friction and the tip bearing components of the resistance.

The computation of the side and tip resistance components from Equation 1 follows the procedure outlined on Figure 1. The process begins by requiring the engineer to make a selection of the material as either cohesive (shear strength measured by a cohesion value, equal to the undrained shear strength in application) or cohesionless (with shear strength governed by an angle of internal friction). This decision is troubling to some geotechnical engineers who feel that the best model for partially saturated soils common across Arizona includes both components; as a result, some designs have been completed in Arizona by combining the results for both a cohesive and a cohesionless component.

The left, or cohesive, side of the flow chart has been reasonably well documented and calibrated for use on the cohesive materials in Arizona. This approach has been shown to agree reasonably well with the results of load tests conducted in the state, although the settlement behavior of these materials does not match the expectations of Section 4.6.5.5.1.1.

However, the applicability of this standard has never been confirmed or calibrated for the coarse materials located in river environments throughout the Arizona deserts. These materials are generally of recent origin, and are remnants of the high energy flood events which typify the ephemeral river environments of the Arizona deserts. Variously

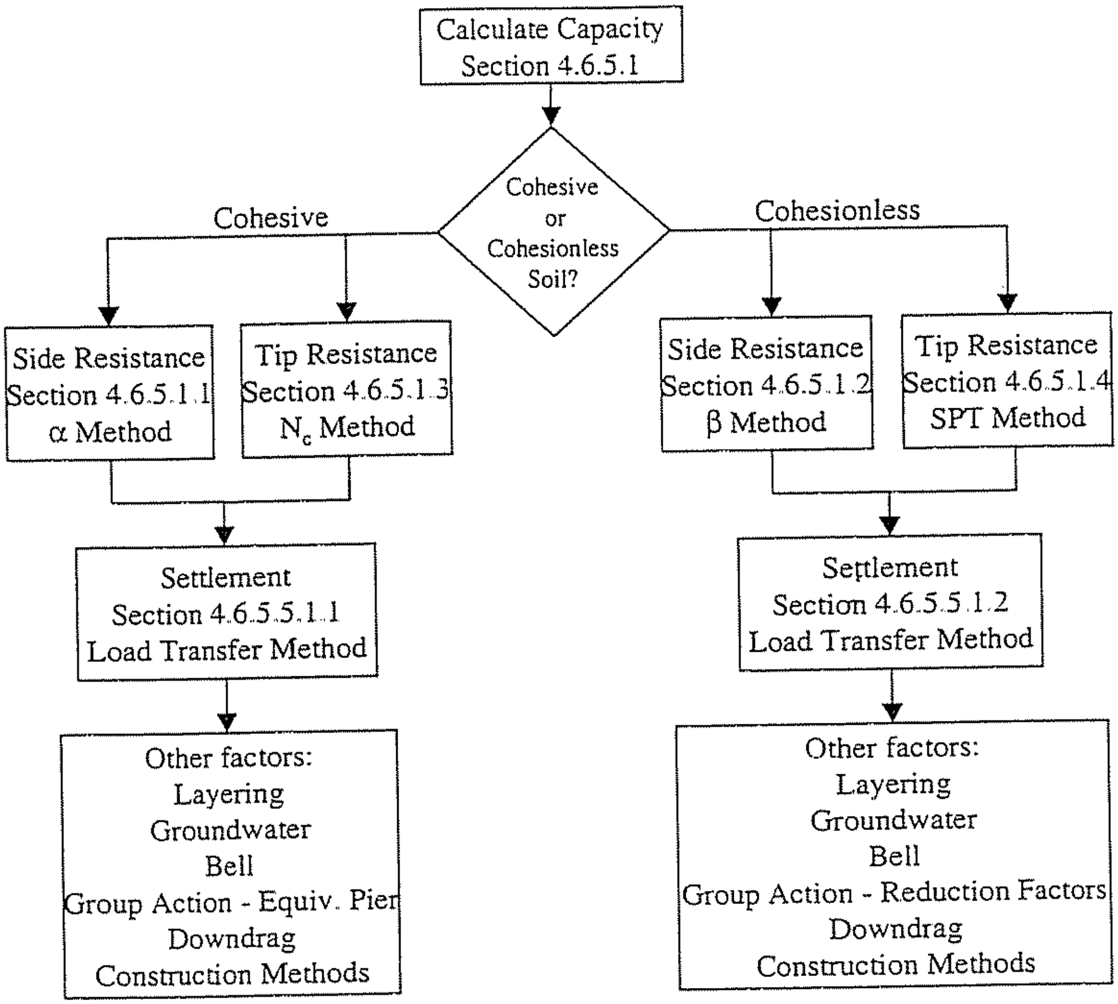


Figure 1: Summary of AASHTO Design Method for Drilled Shaft Axial Capacity

described as "river run," "sand-gravel-cobbles," or "SGC," these materials are very frequently used for support of bridge foundation elements for river or wash crossings, because of their proximity to the water courses. They are typically dense and contain particles as large as boulder-sized materials. Coarse material in the SGC is usually subrounded due to transport, and in most of the Arizona deserts the large particles are extremely hard. Frequently the material is clean and relatively uncemented in the upper portions of the deposit, but often contains low to moderate plasticity fines or cementation that leads to cohesion below a depth of 20 to 30 feet.

These materials are extremely difficult to characterize because they are difficult to impossible to sample and test. The lack of cohesion makes the sampling process difficult, for any soil, but the large particle sizes compound the problem dramatically. Because materials as large as 12 inches or more may be found, samples with a minimum diameter of 40 inches or so would be required. Push or drive sampling methods could not be expected to be successful due to the hardness of the large particles, which means that freezing and coring or hand sampling would be required, both of which are prohibitively expensive even if they could be conducted. Perhaps even more important than the sampling problem is the fact that even if a sample could be obtained, conventional laboratory equipment would be wholly inadequate because of the size of the sample required. Only very specialized research laboratories could be expected to have equipment capable of testing the samples, which would again be prohibitively expensive.

In general, two approaches are adopted in geotechnical practice when sampling and testing of a material is not possible:

A. Field testing
B. Extrapolation of test data and relationships for finer grained cohesionless material.

For the axially loaded drilled shaft problem, an extremely large volume of soil is involved in the process, and of course the best field test that could be conducted is a load test of a drilled shaft of the size expected for the final product. This kind of testing is very difficult and expensive for SGC materials because very large capacities can be developed, so the available field testing is quite limited. ADOT has conducted some field testing of deep foundations. The most relevant is reported by Beckwith and Bedenkop (1973) and includes one site with results for tip resistance on SGC. Additional full-scale testing was reported by Walsh (1990), but the SGC portion of the soil profile was isolated from the test shafts.

Method B above has been used more or less exclusively in past design practice in Arizona. The extrapolation required is not trivial; an excellent model that takes into account all the important parameters is needed to do it well. Most of the models that have been used in the past have not taken a proper accounting of the differences in grain size and density between finer grained sands and SGC, especially as it relates to dilatancy. The most common approach has been a direct extrapolation of the results for finer grained materials (such as those outlined in the AASHTO standard) without any accounting for changes in grain size and density. This approach is probably conservative, although to an unknown degree.

Furthermore, the difficulties in obtaining and testing samples for SGC materials creates problems for ADOT oversight of contracted design work. The selection of soil properties for design typically must be done based on the experience and opinions of the engineers involved. In the absence of standardized policies about the values to be selected, different soil properties and different degrees of conservatism could therefore occur on nearby structures in similar soil deposits.

The AASHTO Standards for cohesionless materials call for calculation of skin friction using Equation 2.

$$Q_s = \pi B \sum_{i=1}^{N} \gamma' z_i \beta \Delta z_i \qquad \text{Equation (2)}$$

Where:

$B=$ diameter of drilled shaft

$\gamma'=$ effective unit weight of soil; i.e., total unit weight above groundwater table and buoyant unit weight below groundwater table.

z= depth below ground surface to midpoint of layer
N= total number of soil layers in profile
β= load transfer factor
Δz= length of layer.

The load transfer factor, β, ranges between a maximum of 1.2 near the ground surface to a minimum of 0.25 at depth, according to Equation 3:

$$\beta = 1.5 - 0.135\sqrt{z} \qquad \text{Equation (3)}$$

The only soil properties which are directly entered into Equation (2), then, are the layer geometry (z and Δz) and the soil unit weight (γ). A similar formulation is reported in the EPRI design manual (Kulhawy, 1989):

$$Q_s = \pi B \sum \gamma' z \left[K(z) \tan\delta \right] \Delta z \qquad \text{Equation (4)}$$

Where:

$K(z)$=coefficient of horizontal earth pressure as a function of depth
δ= angle of friction at the pile-soil interface, typically (0.8-1)ϕ for sand-concrete interfaces.

This formulation has been used in Arizona transportation application for a number of projects known to the research team, and clearly is the same as Equation (2) as long as

$$\beta = K \tan\delta \qquad \text{Equation (5)}$$

In this formulation, the K and δ (or ϕ) values are input for the soil, which allows the geotechnical engineer to make more choices about soil properties. Common assumptions for the SGC materials include $\phi = 42°$ and $K = 1$. Therefore, if we assume that for finer sands δ ranges from 0.8 to 1 ϕ, or 33.6° to 42°, then the relationship between the equivalent β from Equation (5) and β from the AASHTO standard, Equation (3), would be as given in Figure 2.

The calculation of the tip resistance for drilled shafts in the AASHTO standard is a Meyerhof-type formulation taken from Reese and O'Neill (1988). It uses as input an uncorrected standard penetration test (SPT) resistance (N). This approach is generally not used for SGC, because the character of the SGC material makes the SPT result extremely questionable. In fact, refusal N-values are usually experienced. Strictly speaking, one could apply the limiting value of 90ksf presented in Table 4.6.5.1.4A in this circumstance. However, it is more common to apply either a different (lower) limiting value or to proceed with a bearing capacity formulation such as that described by Kulhawy (1989). Once again, the selection of soil properties for use in design is a potentially contentious decision.

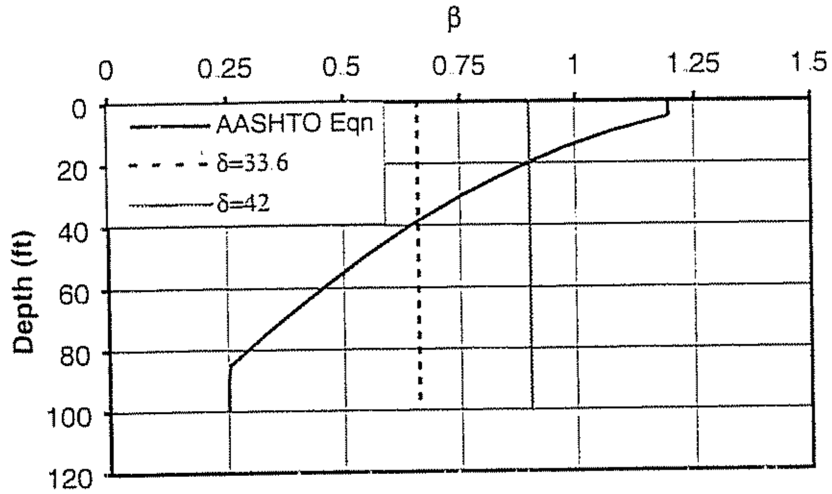


Figure 2: β Values from AASHTO and Common Practice

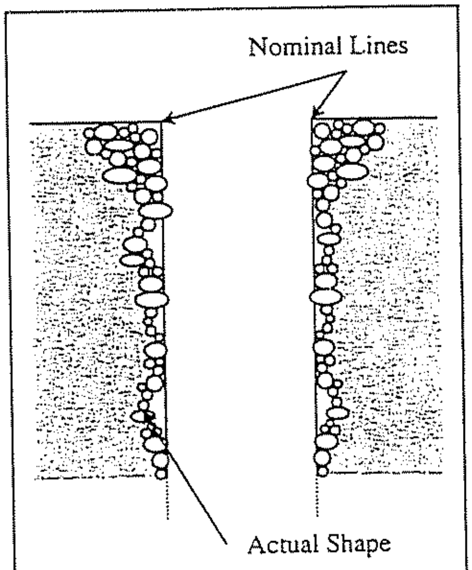
Another approach that is frequently adopted is a design procedure based on the mobilization of the soil resistance to downward movement of the shaft. Following this approach, one obtains mobilization curves for the skin resistance along the sides of the shaft (called t-z curves) and for the tip resistance at the base of the shaft (called q-w curves). These curves may be obtained from a load test or from correlation with similar soils reported in the literature (Reese and O'Neill, 1988 is commonly used and is in fact cited in the AASHTO standards). For a given deflection, the mobilization curves can be used to develop the soil resistance and the resulting load capacity of the shaft. This process can be repeated for a range of deflections to develop a load-settlement curve for the shaft head, and then an allowable capacity selected for the drilled shaft at an acceptable level of deflection. This approach is usually approached with a computer program, commonly the Ensoft product called APILE.

The Relevancy of Dilatancy

A key issue to the proposed project is the appropriateness of current drilled shaft design methods for the SGC materials. It is more or less impossible to judge this appropriateness from an analytical perspective without considering the effects of dilatancy on the response of prototype shafts. The discussion which follows shows why dilatancy is more important for drilled shafts in SGC than for shafts in sand and finer grained materials.

Dilatancy refers to shear induced volume change. It is perhaps obvious that an increase in all-around normal stress will produce a volume decrease in an element of material and conversely a decrease in all-around normal stress begets volume increase or expansion. The effect of an increment of shear stress is not so obvious, however. When shear stress is applied to an element, its volume can either decrease or increase. When it is lightly confined and initially dense, it tends to expand and is said to be dilatant. If it is heavily confined and initially loose, then it tends to densify and is said to be contractive. Thus, whether or not it tends to dilate during shear and by how much depends on how dense the material is initially and how heavily confined it is. It is widely recognized that SGC is typically dense, probably due to the depositional process leading to its formation. At the confining pressures due to overburden and structural loads normally encountered in transportation applications, SGC can be expected to be substantially dilatant.

When a drilled shaft is loaded axially and starts to move downward relative to the SGC around it, a shear surface is established along the surface of the shaft or in the vicinity of the outer surface of the shaft. It is in this region that dilation primarily occurs. The amount of movement required for particles moving in and near the shaft surface depends on the effective particle size and the roughness of the shaft. The roughness of the shaft is indicated in Figure 3. Augering grooves and local caving as well as inward protruding cobbles of various sizes all combine to produce a rough surface. When the concrete is placed, liquid cement paste and latents penetrate radially outward, capturing some cobbles and making them a part of the shaft. This process is portrayed schematically in Figure 4. In the case of SGC this penetration will typically be substantial, though variable.



(a)

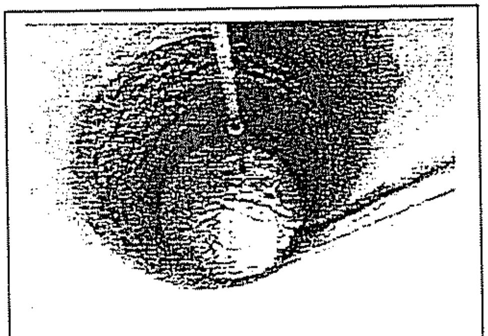

(b)

Figure 3: Condition of Sides of Excavation in SGC, (a) schematically, and (b) from real excavation

Suppose that, in a particular case, all factors which yield roughness and the particle size distribution of the surrounding SGC combine to produce an effective particle size of 4 inches for the material at the edge of the drilled shaft. If the shaft were axially loaded and forced downward 2 inches, then particles around the shaft would be forced to move radially outward a distance on the order of 2 inches, due to the dilatory effect. This outward movement could be accommodated in one of two ways (or a combination of both). First, and perhaps most importantly, outward movement of particles due to dilation is more or less equivalent to cavity expansion and would be accomplished by a

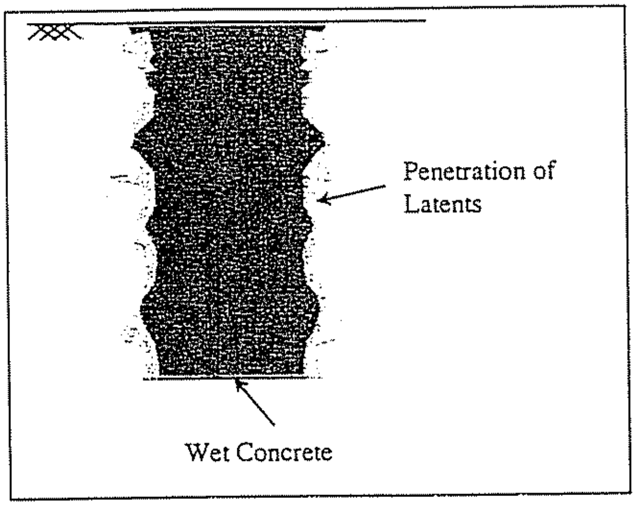


Figure 4: Penetration of Latents into Formation

substantial increase in radial normal stress as the particles are forced outward. The increase in radial normal stress decays radially, but within the radially stressed zone compression (densification) would occur corresponding to the increased radial stress. If the densification were adequate to accommodate the dilation in the vicinity of the shaft surface, then the radial normal stress would achieve some intermediate value between is initial value and an upper bound limiting value. If, however, the material were of very low compressibility and densification were insufficient to accommodate the dilation, then the ground surface would have to heave slightly to accommodate the dilation. In this case, the radial normal stress would reach an upper limiting value, corresponding to the passive condition. In most cases it would be expected that the dilation would be accommodated by some combination of densification of material and heaving of the ground surface.

The buildup of radial normal stress due to dilation is portrayed schematically in Figure 5. Immediately after placement of the concrete the radial normal stress would be the depth times the unit weight of the concrete. After complete set-up of the concrete and loading of the shaft, the radial normal stress would build to an intermediate value as shown, provided that compression and densification of the surrounding material was sufficient to accommodate the dilation. Otherwise, the radial pressure would rise to the upper bound value and the ground surface would heave. It is likely that the actual radial pressure might follow a more complex pattern, perhaps near the upper bound near the ground surface and smaller at greater depths, depicted schematically in Figure 6.

Probably the most important conclusion from this discussion of the relevance of dilatancy is that the amount of radial outward movement during dilation is roughly proportional to particle size. Therefore, although dilatancy would be expected to occur for shafts in sands, the outward movement would be much less. Furthermore, the compressibility of sand would be much more that that of SGC, and the corresponding build-up of lateral stress during loading would be a lot less for sands than for SGC. These considerations tend to support our inclination to believe that the methods used to predict axial capacity of shafts in sand will be quite conservative for use in SGC. In the Work Plan section

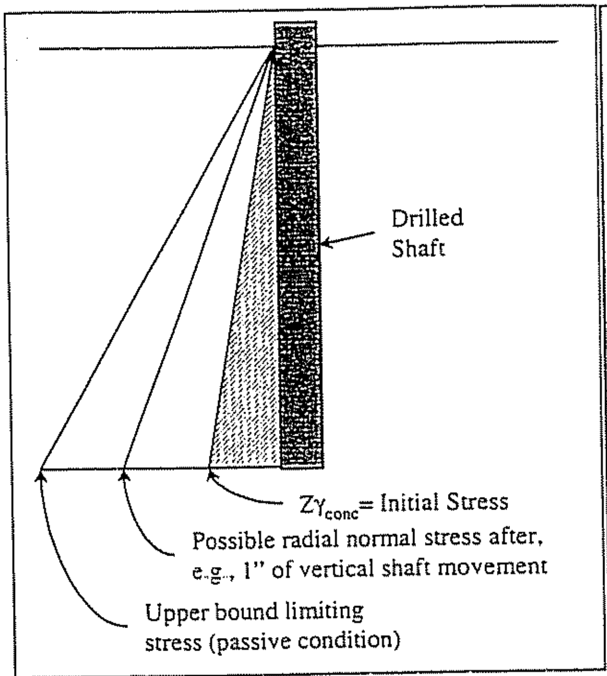


Figure 5: Upper and Lower Bound Radial Normal Stress of Shaft

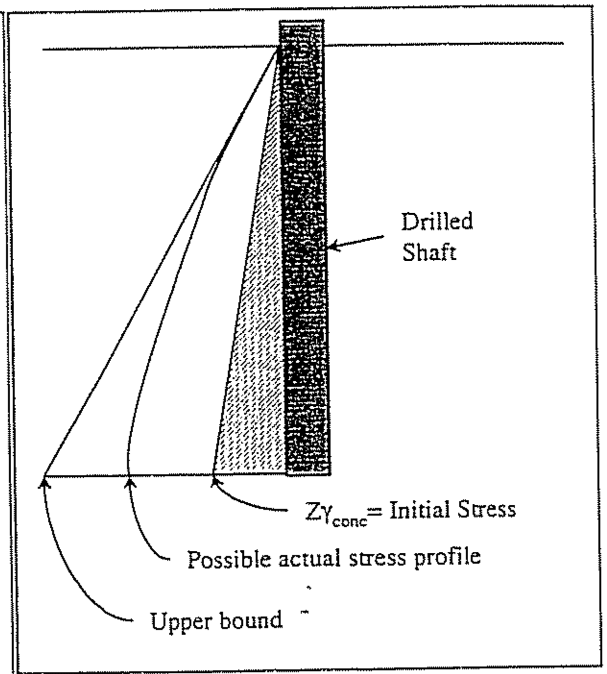


Figure 6: Possible Variation of Actual Radial Normal Stress with Depth

presented later, a description of large scale field shear tests is given. These tests are designed to help quantify the effect of dilatancy in SGC.

Other Issues

A related issue of concern to designers and practitioners is the performance of groups of drilled shafts in SGC under load. AASHTO standards (Section 4.6.5.2.4.2) call for groups to be designed in cohesionless soils using a reduction factor times the individual capacity of each shaft. The capacity is to be reduced using a multiplier of 0.67 at a shaft spacing in the group of 3 diameters, ranging up to a multiplier of 1.0 at a shaft spacing of 8 diameters. An alternative procedure is to use the group equivalent pier method, but this approach rarely controls in materials of the strength of SGC. The source of these multipliers is not given in the standard. These multipliers are considered by many practicing engineers to be overly conservative for use in Arizona soils.

The uncertainty and supposed conservatism of the single shaft design in SGC, combined with similar concerns about the group design procedures, raise the possibility that a more appropriate design methodology for SGC could be developed. It is therefore desirable to consider possible modifications to these procedures for Arizona conditions. These modifications would likely take the form of a set of recommendations for soil properties (or β-values) for SGC soils. These recommendations would need to be flexible and appropriate for a range of gradations and for both uncemented and variably cemented conditions. Ideally, then, some potentially measurable property of the soil in place (such as gradation or seismic velocity) should be related to the recommended values. The comfort level of all concerned will be greatly enhanced by a full-scale test of axially loaded single drilled shafts and groups of drilled shafts in the SGC. To date, only field testing of the tip resistance of drilled shafts in SGC has been conducted (Beckwith and Bedenkop, 1973).

Thus, after making the literature study exhaustive, the next two major tasks are to develop a mechanistic model to predict axial behavior and then to calibrate it. To the extent that full-scale load tests already reported in the literature are representative of the soil conditions, loading geometry, and boundary conditions which ADOT typically encounters, these load tests can be used to calibrate the model. Still better than these load tests from the literature would be actual load tests in Arizona, tailored to ADOT specifications. Thus the last major task for the present project is the design of a field load test for full-scale pile groups. If possible, due to combination with other work ongoing with SPR 483, the tests will be conducted as well.

The significance of the work rests on two important facts:

1) Drilled shafts have become the preferred deep foundation element for the State of Arizona.

2) There is a consensus among practitioners inside and outside of state agencies that currently available drilled shaft design methods and policies are substantially conservative for the conditions and usage normally encountered in Arizona.

Provided a sound, well-founded design methodology for drilled shafts in SGC can be developed from this research effort (and that currently-used methods are substantially conservative, as expected), ADOT and other constructors in the southwest especially can potentially realize very significant foundation construction cost savings on new structures.

Objectives of the Project

The primary objective of this project is to develop recommendations for design methods and soil properties for axial loaded drilled shafts in Arizona SGC soils, and to develop plans for and execute needed field verification of those recommendations. This objective will be accomplished by completing the following activities:

(1) Summarize the content of the literature, the activities of other researchers, regulators, and practitioners into a complete listing of analytical approaches to the axially loaded drilled shaft group problem, and any methodologies for the design of single shafts in coarse cohesionless and cemented materials.
(2) Describe and categorize the conditions under which drilled shafts in SGC materials are used in transportation applications in Arizona.
(3) Analyze typical Arizona transportation applications using the most promising methods identified, tailored to Arizona soil conditions.
(4) Develop recommendations for appropriate design methods for Arizona transportation applications based on these analyses.
(5) Make detailed plans for field verification of these recommendations and execute field load testing in conjunction with the lateral load testing program.

(6) Produce reports of all activities, with appropriate documentation and letters to allow changes in ADOT practice, training and outreach to practitioners in the Arizona geotechnical and bridge structural community, and external publication.

Work Plan

Introduction

The following work plan has been developed to accomplish the objectives for this project. The proposed project will include the design of a load testing program as a minimum. However, the research team is currently developing plans and financing options for load testing for the development of lateral load procedures (SPR 483, Optimization of Drilled Shaft Group Spacing). This load testing program may be conducted over the same time period, and could be modified to include testing for this project as well. This proposal has been developed with this idea in mind.

The research program is therefore being conducted with very specific and measurable goals. The project needs to be conducted in a timely manner, and must produce specific documents which further ADOT's need for cost-effective design methods while still assuring the safety of the traveling public. These documents must be accepted by the engineering community which performs design work for ADOT, by ADOT staff, and by FHWA staff in their oversight role. The approach proposed by ASU has been tailored to ensure that each of these actions is completed.

Therefore, the major challenges which face us arise out of the very nature of this project. The outcome of this research is expected to be a change in ADOT policy on drilled shaft design and, in time, a change in the AASHTO policy. Such changes will require a combination of academic thoroughness to convince the national audience, with a thorough grounding in practice to convince the local audience. Our approach has been designed to accommodate both of these techniques using the following strategies:

- Assignment of personnel with national reputations in geotechnical engineering, and in particular with the specific geotechnical issues of deep foundations, analytical and field modeling, and Arizona soil conditions.
- Assignment of personnel with significant experience working for or with ADOT on transportation design and construction projects.
- Development of a steering committee of local practitioners to review and guide the documents produced, in order to develop local "buy-in" as the project proceeds.

Clearly, these strategies point out the importance of the team which has been assembled to the ultimate success of this project. The qualifications of the team will be spelled out in more detail later in this proposal, but will be summarized below in light of the specific

needs outlined above. The proposed organization of staff for this project is presented on Figure 7.

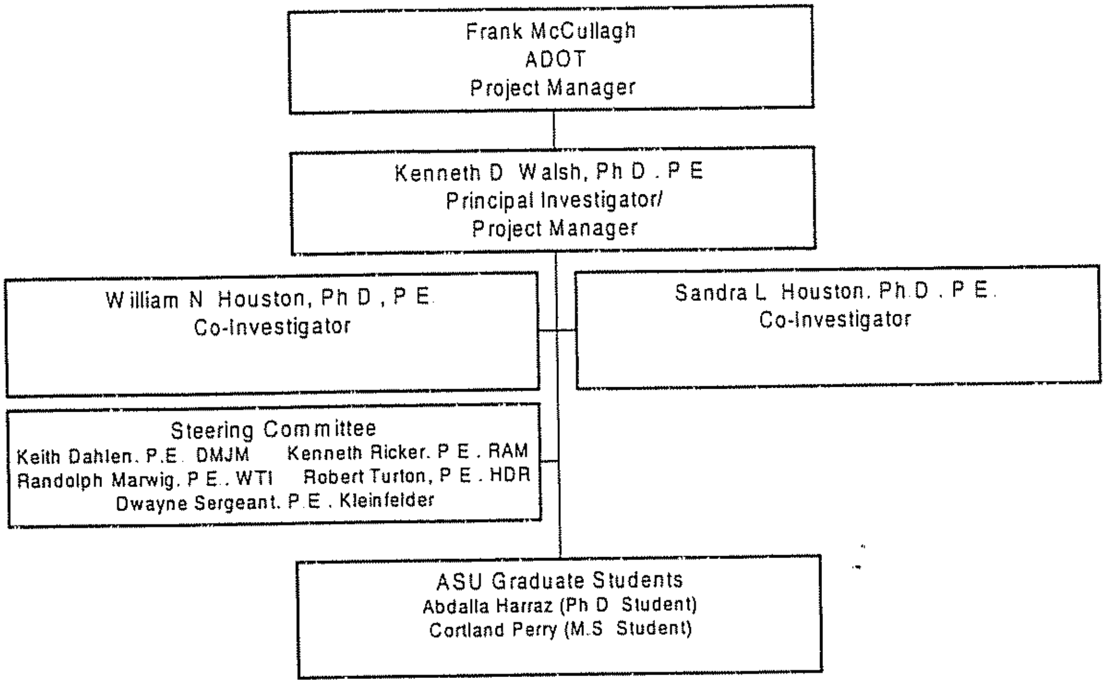


Figure 7: Proposed Staff Organization for the Project

The project manager/principal investigator will be Dr. Kenneth D. Walsh, P.E., an associate professor of construction at Arizona State University and a former geotechnical consultant in the Phoenix area. As such, he is well aware of relevant ADOT documents and the application of current ADOT and FHWA design policy. Dr. Walsh is published in the area of drilled shaft behavior, and has participated in the design of a number of drilled shaft projects in the urban and rural highway systems. Dr. William Houston, P.E., is a professor of civil engineering at ASU, and will serve as a co-investigator for this project. Dr. Houston specializes in the development and application of field and laboratory testing methods, analytical methods, and soil-structure interaction problems. Dr. Sandra Houston, P.E., professor of civil engineering and chair of the Department of Civil and Environmental Engineering at ASU, will also serve as a co-investigator. Her national and international reputation has been built on the development of soil mechanics for arid soils, and she has been active in teaching and research in the application of advanced analytical methods in geotechnical engineering.

Quality control of the developing recommendations is a very important component for the success of this project. In this usage, quality control implies both the technical accuracy of the data compilation and analysis conducted, but also the acceptability of the work to the design community. The technical accuracy will be the responsibility of the PI and the co-I's on the project. All graduate research assistant work will be carefully reviewed by the faculty team. The acceptability to the design community will be directly assessed by the direct involvement of design practitioners on a steering committee for this project. A steering committee has been developed to assist us in the completion of this project. Members of the committee include:

- Mr. Robert L. Turton, P.E., of HDR Engineering, Inc.
- Mr. Keith Dahlen, P.E., of DMJM, Inc.
- Mr. Kenneth Ricker, P.E., of Ricker Atkinson McBee and Associates
- Mr. Dwaine Sergent, P.E., of Kleinfelder, Inc.
- Mr. Randolph Marwig, P.E., of Western Technologies, Inc.

The steering committee will meet with the investigators, and will provide straw-man reviews of all documents. The committee will provide access to their project files to allow accurate determination of the design approaches used on existing structures, and will provide input on the practical implications of the developing recommendations. We believe that the inclusion of the steering committee as partners to the research will facilitate rapid dissemination and acceptance of the results.

Approach

This section includes details of the approach proposed to accomplish the research objectives. The summaries of each major activity include a summary of the proposed deliverable for that activity. The work will be conducted in 10 tasks, which generally follow the outline given in the RFP, with some regrouping and reordering (Figure 8).

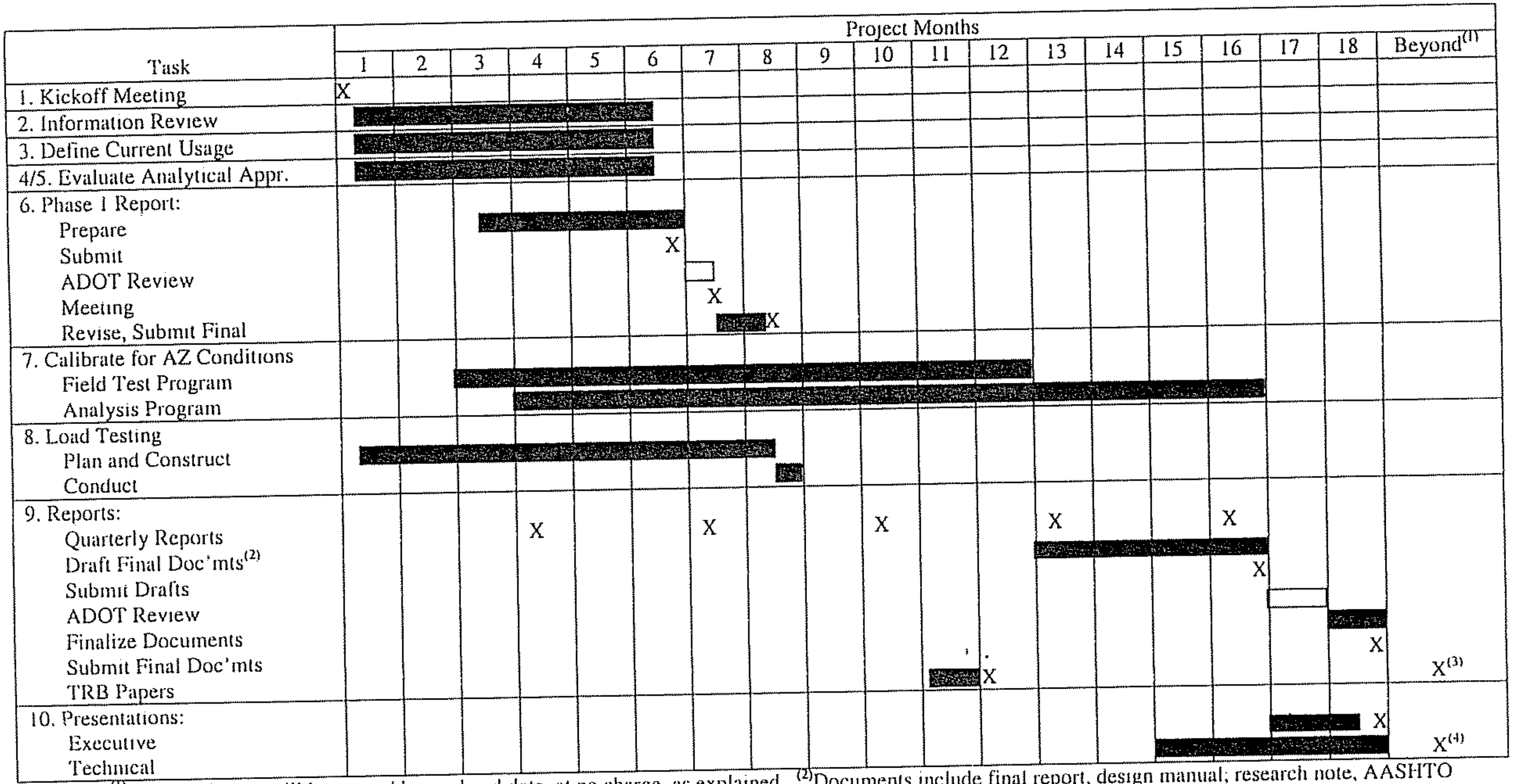
There are two distinct phases to this project. The first phase consists of Tasks 1 through 6. Following a kickoff meeting (Task 1), the project team will complete an exhaustive literature search. Tasks 2, 3, and 4/5 will be completed concurrently, leading to the development of the Phase 1 Report (Task 6). This report will summarize all of the information developed from the literature and our surveys of practice and usage, and make final recommendations for the direction and content of the remaining tasks. The report will be submitted 6 months after project initiation.

After a two-week period for ADOT review of the Phase 1 Report by the TAC, the project team will meet with TAC. At this meeting, the TAC will provide comments, and a general discussion of the work to be done in the remaining tasks will be held. Two more weeks will be allotted for any necessary revisions of the report and acceptance by ADOT.

The Calibration and Load Testing Tasks (7 and 8) will be major undertakings for the proposed work. Because these tasks will require so much time, we propose to start on them during the development of the Phase 1 Report. This order of tasks will allow a more timely development of design procedures and parameters. Furthermore, one of the lessons of SPR 483 was that the finite element modeling contemplated for the Analysis Program in Task 7 will require very long lead times to satisfactorily complete. For all these reasons, we believe that temporal separation of the Tasks on either side of the Phase 1 report is not as practicable or desirable as it was for SPR 483, and we have designed the workflow accordingly, as shown in Figure 8.

The final deliverables will include a final report, a design manual for axially loaded drilled shafts in SGC Soils (with examples), a research note, a proposed revision to AASHTO 4.6.5.1, a change letter for the ADOT Preliminary Engineering and Design Manual, TRB papers and other papers, an executive presentation to the Research Council, and an annotated technical presentation to convey the recommendations to practitioners. A detailed summary of our plans for each task follows Figure 8.

Figure 8: Work Task Time Schedule



Notes: (1)Some activities will be carried beyond end date, at no charge, as explained. (2)Documents include final report, design manual; research note, AASHTO revision, and PE&D Manual Change Letter. (3)TRB Deadline in August. One paper will be submitted in Year 1 documenting literature and usage outcomes. Additional paper will be submitted in Year 2 summarizing entire study. (4)Technical Presentations will be made largely after end date. "X" indicates one-day event or delivery date.

Task 1 – Kickoff Meeting

The project will begin with a kickoff meeting between the Technical Advisory Committee (TAC) for Project SPR 493 and the Project Team. The Team will be represented by the Principal Investigator (PI) and co-investigators, the graduate research assistants, and members of the Steering Committee. The agenda for the meeting will be developed by the PI and the ADOT Project Manager. The objective for this meeting will be to complete introductions of all TAC members and the Project Team, to review the scope of work and the proposed work plan, to identify key data needs within ADOT and contact persons for obtaining that data, and to finalize the project schedule.

Task 2 – Information Review

This task will consist of a thorough review of the technical literature related to axial loads on deep foundation elements. The following sources of information will be assessed:

Technical Literature: The literature will be consulted for published recommendations for methods of analysis of drilled shaft vertical capacity in coarse granular materials, published methods for assessing the capacity of a group of drilled shafts under vertical load, and published load test results for vertical loads on drilled shaft elements in coarse granular materials.

Unpublished Reports: Any methods of analysis used for vertically loaded drilled shafts in coarse granular materials and/or vertically loaded drilled shaft groups, or relevant load tests never reported in the technical literature that we can identify will be used to compare to the results obtained from the analytical methods identified in the technical literature. The most likely source for these reports will be state DOT's. Our survey of the practice for laterally loaded drilled shaft group criteria and procedures demonstrated that it is time-consuming to make contact with the appropriate person in each DOT. However, any inquiries which do bear fruit will be quite helpful, so this survey will be completed. This activity should be carried out over all state DOT's.

Ongoing Research: We will talk with recognized researchers in other states to develop their opinions and any direction to published or unpublished results. We will attend the Association of Drilled Shaft Contractors (ADSC) Workshop for university professors (July, 2000) on drilled shaft technology and incorporate any relevant components which are forthcoming.

Experience of Engineers: We will form a steering committee of local engineering practitioners of geotechnical and bridge structural engineering. The steering committee will have two functions, a) to review the activities and findings of the researchers and advise on the best route to use of those findings in practice, and b) to provide input into their current practices and opinions relating to the development of the vertical capacity of a piles in SGC and in groups in transportation applications in Arizona. Through the steering committee, a cross-section of Arizona practice should be developed. This will be augmented with additional interviews of engineers in private practice and in ADOT employ in Arizona. As part of our survey of all state DOT's we will determine the actual practice and application of the AASHTO recommendations in other jurisdictions.

DELIVERABLE: Very complete description of axial design methods for drilled shafts which may be appropriate for SGC, with recommendations from the literature for the appropriate properties or values for use with each method (if available). In addition, we will seek to find published and unpublished load tests and the design methods in common use for Arizona. Tests of groups of drilled shafts under axial load will also be obtained. All of the information collected in this Task will be summarized in charts or tables as appropriate in the Phase 1 Report.

Task 3 – Define Current Usage

The objective of this task is to develop typical applications for vertically loaded drilled shaft groups in Arizona and applications of drilled shafts, whether singly or in groups, in SGC conditions. It is expected that drilled shafts used in SGC will typically be of larger diameter than in other soil conditions. As-built drawings for the structures identified, including the drilled shaft groups, will be sought from ADOT files. Information to be collected for each drilled shaft (or drilled shaft group) will include the shaft diameters and lengths and soil boring logs and geotechnical testing results. For drilled shaft groups additional information will be collected, including the number and arrangement of shafts in the group, pile spacing within the group, and the location of the cap relative to the final (or design, in cases with scour) ground line,.

For each drilled shaft or drilled shaft group, we will attempt to identify the vertical load resistance design process from information in ADOT files, design consultant files, or interviews with the designers. It was our experience with SPR 483 that this kind of information is extremely difficult to find, but we will collect what we can. The specific intent of this effort will be to describe, in detail, the process used in design to develop the vertical capacity of the shafts

DELIVERABLE: A database of drilled shaft group geometries, soil conditions, and vertical resistance design methods used for a number of transportation structures in Arizona. From this database, we will identify two to four "common" drilled shaft groups.

Task 4 – Evaluate AASHTO and LRFD Procedures

This task has been combined with Task 5.

Task 4/5 – Evaluate Analytical Approaches

This task includes three subtasks. First, all methodologies identified under Tasks 2 and 3 will be examined with respect to their usefulness in predicting the axial capacity of drilled shafts in SGC soils or the capacity of shaft groups in other conditions identified in Task 3. As has been pointed out, existing methods to be considered will include the AASHTO β method, a similar approach invoking K$\tan\delta$ in place of β, the t-z driven computer programs such as APILE, the methodologies recommended in the AASHTO LRFD Commentary, and perhaps other analytical or chart solutions. In this Task, we will conduct analyses of common drilled shaft sizes (to come from Task 3) using all methods.

To the extent possible, we will compare the performance of the analytical solutions with measured results for full scale load tests in coarse granular materials, although we are not optimistic that the database for test results in SGC type materials will be large. As an example, a preliminary review of the literature revealed a few tests on granular deposits, but the results were largely from finer grained material than the SGC of Arizona (e.g., Sharma and Joshi, 1988) or did not include skin friction behavior (Beckwith and Bedenkop, 1973). Similar analyses will be conducted for drilled shaft groups under axial load, although the literature on full scale tests in coarse granular soils is expected to be even more sparse.

Second, the finite element method (FEM) will be evaluated and utilized as a research tool in the study of large diameter drilled shafts in SGC. As part of SPR 483, a comparison of more than 100 FE codes was made, and the ABAQUS code was selected for that project. Therefore, a search of the available FE codes will not have to be repeated and the ABAQUS code will be used for SPR 493. The research staff is already trained and up to speed on ABAQUS. The FE studies will be used only during the research phase and will not be recommended for routine design practice. The FE results will be used to expand the database for large-scale shafts in SGC, an expansion which is needed due to the small amount of field test data available.

Third, the results of the first and second subtasks above will be used as a basis for selection of a design methodology which will be generally consistent with a) the meager database for field testing and b) the results of the FE analyses and other analytical studies conducted in the course of the research. It is also anticipated that the design methodology will be less conservative and more realistic that the methods developed for fine-grained materials.

DELIVERABLE: A recommendation for design methods which are likely to prove effective and to be further developed in later tasks.

Task 6 – Phase I Report

In this task, the project team will prepare a Phase 1 Report containing the information developed in tasks 1 through 5 for review by the project TAC. It will include a detailed work plan for the remainder of the project that clearly articulates our proposed approach for completing the remaining portions of Tasks 7 and 8. The report outline will depend to some extent on the progress of the work, but at this time we expect it to include:

1. Introduction, with a brief summary of the report.
2. Summary of Literature and Practice, with an emphasis on practice in Arizona and results from tests in conditions similar to those common in Arizona; to include tabular presentation of all recommended soil properties encountered for use in coarse grained cohesionless or cemented soils.
3. Summary of Historic Use, describing the drilled shaft geometries (whether used singly or in groups) and design processes (if available) of drilled shafts used for the resistance of primarily vertical loads in transportation applications in Arizona.
4. Analytical Approaches, describing the application of the methods outlined in Section 2 to conditions common in coarse-grained soils in Arizona.

5. Data Gaps, outlining the areas in which Arizona conditions are not well represented in the literature or contemplated in published design methodologies.
6. Recommendations for Finishing Study, containing specific recommendations for what ought to be completed in the remainder of the research program. It is expected that these recommendations will include analytical modeling (including finite element modeling), performance of field material characterization tests, described under Task 7, and large-scale field load testing, described under Task 8.

The report will be delivered six months after project initiation, and will be reviewed by the Steering Committee before it is submitted to ADOT. Two weeks after submittal, we will meet with the TAC to discuss the findings. This meeting will include an opportunity for the project team, including the steering committee, to share ideas about the appropriateness of the recommendations in the Interim Report and detailed comments about ways to improve the Interim Report. An additional two weeks have been allocated after this meeting to revise the report and obtain final acceptance from the TAC.

DELIVERABLE: Phase 1 report, meeting with TAC, and development of consensus for the steps to be taken to complete the research.

<u>Task 7 – Calibrate Analytical Approach for Arizona Conditions:</u>
The primary objective of this task will be to develop a design procedure and parameters for axial loading of drilled shafts constructed in SGC layers according to ADOT practice and under typical Arizona conditions. The design method developed will be compared to those presented in the AASHTO and LRFD manuals.

Basically, calibration of a design method amounts to comparing the outcome of the design process to measured responses obtained from large-scale field tests. For example, for the SPR 483 project it was possible through diligent search of the literature to find some seven cases for which measured results were obtained for both single shafts and groups of drilled shafts. Thus, for this project, it is possible to straightforwardly calibrate the proposed lateral design method(s) be ensuring that the design method(s) produce results that are consistent with the measured group responses.

For the SPR 493 project, the number of cases for which data leading to skin resistance in SGC can be found is expected to be sparse. Even more rare will be those cases for which axial load responses on both single and groups of drilled shafts are available from the same site. Nevertheless, an exhaustive search for such data will be completed, and hopefully will be fruitful. It is anticipated, however, that the database of measured responses will need augmentation from FE analyses and other analytical models.

The specific application activities to be conducted for this task include a Field Test Program and an Analysis Program. These activities will be described in more detail below.

Field Test Program

Due to the large particle sizes of the SGC, essentially all testing will be done in the field. A minimum of 6 sites will be chosen for field testing, including the SGC site where the groups of drilled shafts are to be located. The sites will be chosen so as to span the gradation and general characteristics normally associated with SGC materials. Most or all of the sites will be within 30 miles of the University. A variety of field tests will be performed at each site as follows.

1) In-situ density measurements: At each site the dry density (γ_d) will be measured by (a) creating a flat surface in the SGC; (b) excavating a large hole with a backhoe and saving and weighing the material removed; (c) lining the hole with plastic; and (d) measuring the volume of water required to fill the hole. The test is rather similar to the sandcone density test, but uses water rather than sand as the medium for measuring volume. This substitution will be made because we anticipate that the volume of the hole will be rather large (on the order of 50 gallons) in order to make an accurate accounting of the large particle sizes. Because of the large volume, calibration of the density of the falling sand in a typical sandcone test would be problematic.

2) Gradation tests: At each site the gradation will be measured for the material excavated for the in-situ density determination. At least 2/3 of the largest boulders/cobbles/coarse gravel will be measured and weighed in the field, and only the remaining finer fraction will be returned to the lab for sieving. This procedure will be followed simply for logistical reasons, due to the large sample size.

3) Seismic velocity measurements: At each site P-wave velocity will be measured with multiple geophone spacings so as to evaluate V_p for depths up to about 30 feet. Of course a check will be made to see if near-surface V_p correlates with near-surface density or gradation. The research team is aware of the shortcomings and limitations of the use of seismic velocity to characterize a site and is not normally prone to recommend the soil use of V_p for this purpose. However, for the case in point, the large particle size of the SGC makes sampling and lab testing (certainly undisturbed testing) impossible, and the choices among alternatives are limited. Therefore, it is our intention to evaluate V_p and gradation as indicators of soil mass compressibility and axial resistance for drilled shafts.

4) Large-scale direct shear tests: A minimum of four such tests will be performed, two at the shaft group site and two and other sites. The research team has developed and used a large-scale direct shear box (4' X 4'), and this apparatus is available for this project. It has been used for testing SGC (Houston, et al, 1995). The intended test set-up is indicated in Figure 9. A shallow depression will be excavated and backfilled with concrete. Small boulders, cobbles, and coarse gravel will be hand-placed at the surface of the wet concrete, with their flatter surfaces normal to the shear direction, in accordance with their usual orientation in the side of a drilled shaft hole. After the concrete has set up, additional material will be initially hand-placed and then dumped into the shear box and compacted to approximately site density. Either drilled shafts

and reaction beams or boxes of SGC will be used to apply normal loads. The test results of primary interest will be:

1) Amount of dilation for 0.5", 1", and 1.5" of shear movement – for confining pressures expected to be in the reasonable range.

2) Amount of confining pressure required to hold dilation down to 0.5", 1", and 1.5" – for probable design values of shear movement.

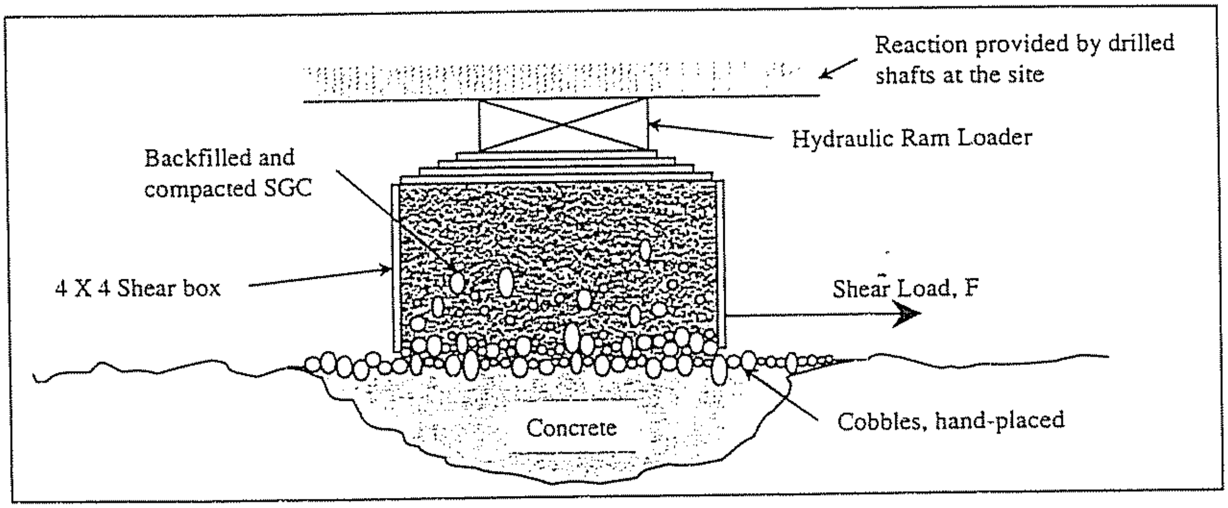


Figure 9: Schematic Elevation View of Field Direct Shear Test

Analysis Program

The proposed analyses may be generally described as follows. All of the data collected in all of the field tests described earlier will be reduced, summarized, and analyzed. Correlations between measured parameters will be sought. In particular, the best parameters to describe gradation and to relate it to dilation tendencies will be studied. A list of specific subtasks is as follows:

1) In-situ densities will be analyzed from two standpoints. First, any relationships between gradation and density will be explored. It is generally assumed that more well-graded materials achieve higher densities. Relationships between density and maximum and/or mean grain size will be evaluated.

2) The direct shear tests will yield specific data for each material tested relative to dilation tendencies. The importance of gradation and compressibility to the dilation process will be quantified.

3) Data from the seismic velocity measurements will be analyzed in several ways. First, algorithms for extrapolating and interpolating the velocities (and corresponding moduli) vertically and laterally will be developed. Conventional interpretations of seismic velocity measurements call for simplification of profiles into layers of constant velocity, which is satisfactory for most uses. The research team has also

developed models of non-linear variation of velocity with depth, which may prove to be useful for SGC. The second major component of the seismic velocity analyses is the conversion of velocities to moduli and the utilization of these moduli in quantifying compressibility. Recall earlier discussions which pointed out that compressibility bears heavily on the maximum radial compressive stress which can develop around the axially loaded drilled shaft.

4) The large-scale direct shear tests will serve more than one purpose. The most obvious outcome from the tests are data leading to ϕ values, and cohesion if present. Second, these tests will serve as the primary source of dilation response data. The associated subtask under analysis is to couple the information on compressibility and the direct shear data on dilation to arrive at realistic shearing resistance values on or near the surface of the drilled shaft under prototype conditions.

5) Finite element analyses will play a prominent role in the analysis program. First, finite element analyses of prototype vertically loaded shafts will be used to relate moduli to compressibility and to help perform the coupling described in subtask 4 above. Second, finite element analyses will be used to evaluate group effects by analyzing vertically-loaded single shafts (including the matching of any available load-settlement curves) first and then repeating this analysis for a group – using the same material properties. These analyses will lead to FE-generated group reduction factors.

DELIVERABLES: This task will lead to the development of recommendations for soil parameters and/or means of establishing those parameters in practice at a given site. Of course, the methods proposed for this task are research oriented (e.g. large-scale direct shear testing), and simplified methods for use in practice for developing site specific parameters will be needed. It is anticipated that resulting recommendations will be based on gradation, seismic velocity, and/or geographic/pedogenesis factors. In addition, a trial set of group reduction factors based on FE testing will be developed.

<u>Task 8: Load Testing:</u>
It is tentatively planned to coordinate and in fact merge the load testing program for vertically loaded drilled shafts with the field load testing program for laterally loaded groups of drilled shafts. The savings associated with this merger is obvious, given the substantial cost of getting single and groups of 36-inch drilled shafts constructed in the ground with caps. Because of this overlap (and because the overlap has been anticipated for some time) the combined field load test program is already planned and designed and has been presented in the Draft copy of the Final Report on SPR 483, submitted to the TAC for that project on July 7, 2000. Accordingly, only a very brief description of the field load test program will be presented here.

Figure 10 shows a plan view of two groups of six-shafts each, to be constructed at an SGC site. The four single shafts (spaced at 24' x 42') serve 3 purposes:

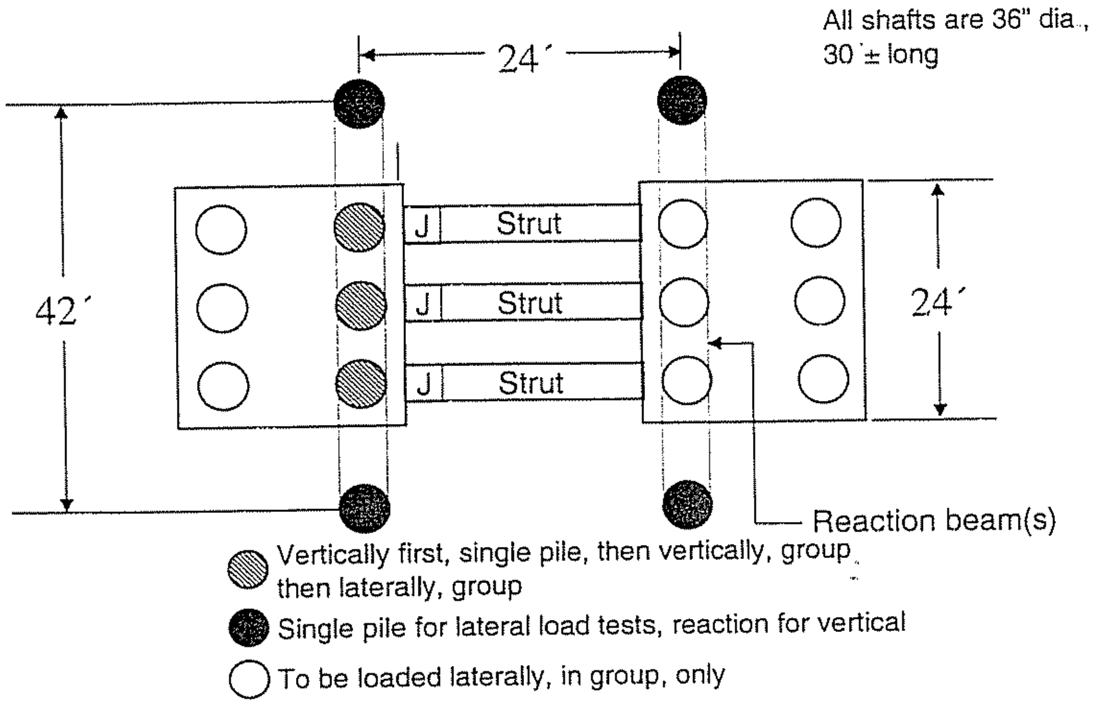


Figure 10: Schematic Plan View of Load Test Arrangement

a) All four will be laterally loaded as a first step, to get the average and range of the single shaft response to lateral load.

b) The two single shafts on the left will be used as a reaction for vertically loading the center cross-hatched shaft.

c) A small cap will then be case over the three cross-hatched shafts and vertical load will be applied to the small cap to evaluate group effects, again using the two single shafts on the left for reaction.

The loading sequence outlined above carries the program to the completion of the vertical loading. The final steps consist of casting the remainder of the caps and then loading both groups laterally, simultaneously. Lateral loading is accomplished through use of large diameter steel pipes as struts (with steel plates on the ends) and hydraulic rams (jacks). When lateral loading of the two groups occurs, all three hydraulic rams are used.

A full complement of instrumentation will be used, including pressure transducers, LVDTs, tiltmeters, strain gages, and surveying equipment. This instrumentation system, described more thoroughly in the SPR 483 Final Report, will provide all measurements needed to quantify vertical and horizontal deflections, rotations, and bending moments. In the vertical loading mode, the strain gages in the shafts will indicate the rate of transfer of vertical load to the surrounding material by friction. When the cap (with three shafts) is loaded vertically, the strain gages in the shafts will help in the estimate of the percentage of load transferred by bearing on the base of the cap.

DELIVERABLE: Load testing will demonstrate the accuracy and acceptability of the design methods outlined in the Phase 1 Report and the parameters developed in the activities described for Task 7.

Task 9 – Reports

A number of final reports and documents are described in the Solicitation, and we have chosen to describe our approach to completing all of them in this Task. The Phase 1 Report was described under Task 6, however, as it occurs at a different time. All reports and engineering data transmitted to ADOT will bear the seals of the principal investigator and the co-investigators. A summary of each document follows.

a. Quarterly Progress Reports – At the end of each calendar quarter, we will submit a report describing our progress to date. We will summarize the completion status of all tasks, and describe any problems we are encountering along with strategies for overcoming those problems. Project administration details will also be provided, including the percent completion, expenditures, and an update of the Team Member Hourly Effort By Task. The report will be mailed to the TAC.

b. Draft Final Report – A final report summarizing all activities and recommendations will be submitted in draft form two months before the end of the project. The format of the document will follow applicable ATRC and FHWA guidelines. The final document will, of course, be shaped by the activities described in the previous tasks. However, the final report will have the following tentative outline:
   1. Executive Summary
   2. Introduction, with a brief summary of the report.
   3. Summary of Literature and Practice, with an emphasis on practice in Arizona and results from tests in conditions similar to those common in Arizona.
   4. Summary of Historic Use, describing the design processes and drilled shaft geometries in transportation applications in Arizona.
   5. Summary of field and lab test data.
   6. Analytical Approaches, describing the application of the methods outlined to conditions common in Arizona.
   7. Results of Analytical Modeling, containing specific recommendations for design methodology for use in Arizona, based upon analysis of the literature results and new research conducted.
   8. Plan for Full Scale Load Testing, containing specific recommendations for the necessary equipment to be acquired, instrumentation strategies, test procedures, analysis methods, and proposed locations for full-scale testing
   9. Assuming the vertically loaded drilled shafts field testing program is merged with the laterally loaded drilled shaft field testing program as proposed, vertical load testing will be performed as a part of this project and those results will be reported.

10. Conclusions and recommendations, conveying concisely recommendations for appropriate factors for design methods for single and groups of drilled shafts under axial load in SGC in Arizona.

c. Design Manual – The design manual will outline the recommended design methods in detail, with example design calculations. This manual will be similar to the one developed for the design of laterally loaded drilled shaft groups.

d. Draft Research Note – A research note will be developed to summarize the project, including the background and approach, a summary of the findings, and recommendations for design methodologies. The note will be four pages or less in length.

e. Draft revision recommendation for AASHTO Standard Specifications for Highway Bridges, Section 4.6.5.1 – The results of this research will be used to develop recommended revisions to the AASHTO recommendations.

f. Change Letter for ADOT Materials Preliminary Engineering and Design Manual – ADOT communicates its design policies with the geotechnical consulting community largely through the Materials Preliminary Engineering and Design Manual. Changes in policy are communicated through Change Letters, which are transmitted to subscribing firms on an as-needed schedule. As such, the manual is a key implementation vehicle for the recommendations of this research. We will prepare a Change Letter to be used by the Materials Group to communicate the revised group reduction factors.

g. TRB Paper – A paper will be prepared for submission to the Transportation Research Board (TRB). The deadline for this submission is typically in August. We believe that two submissions are in order. The first will include a summary of the results of tasks 1-6, and will primarily present a summary of the Phase 1 Report. This would be submitted to TRB in August, 2001, while Tasks 7 and 8 are ongoing. The second will provide a summary of all results and recommendations, and would be submitted in advance of the August, 2002, deadline. Both documents will be submitted to the TAC for review and comment before submission to TRB, and the final paper will incorporate comments. We propose to submit these papers for publication and presentation at the TRB meetings in January 2002 and 2003. Furthermore, we believe that a paper based on this study could also be submitted to the ASCE Journal of Geotechnical Engineering in 2002 or 2003, and propose to develop such a paper as well. Participation and assistance of the Project Manager, TAC, and the steering committee will be acknowledged in these papers.

After a preliminary review by the Steering Committee, all documents will be submitted to the TAC in draft form for review and comment. The technical papers (item g above) would follow a slightly different schedule determined by TRB deadlines, but the balance of the documents would be submitted to the TAC (and such other bodies at ADOT as are requested by the TAC) two months before the scheduled end date of the project, in sufficient numbers for appropriate distribution. Upon receipt of ADOT comments, we will revise all documents to reflect comments and submit final drafts within the remaining time. Camera ready copies of documents to be maintained in the ADOT Library will be provided, and electronic versions of all documents can be delivered if desired. Library storage documents will require 10 copies for the library, and we assume that 10 to 15 copies of each document will also be needed for internal distribution within ADOT Materials and the TAC. ASU maintains the ability to provide Internet publishing of such documents as ADOT may desire, as well, for an additional avenue for access by interested parties.

DELIVERABLE: The various documents listed in final form, incorporating comments from the TAC and others within ADOT.

Task 10 – Presentations

Executive Presentation

The principal investigator, assisted by other members of the project team, will make an executive presentation to the Research Council at the conclusion of the project. The presentation will include a summary of all work conducted, a description of all analyses conducted, and a summary of recommended design methods based on this study.

Technical Presentations

The Solicitation requests a presentation of the materials developed in the research to be delivered to ADOT and non-ADOT persons who might be interested, for the purpose of assisting in the transition into practice. We propose to make such a presentation as soon as practical after the end of the project. Even though this activity will occur after the project end date, no additional funding will be requested for this or other presentations to be made by the research team. We believe that scheduling a single presentation for all of the potentially interested persons might be extremely difficult, and so propose to provide several deliveries of the presentation over the 6 month period after the completion of the project, as a service to ADOT and the profession. Potential avenues for delivery of this presentation include Arizona Geotechnical Group meetings, Arizona Section ASCE Section or Branch meetings, Structural Engineers Association meetings, Roads and Streets, and other seminars which could be scheduled internally at ADOT, perhaps as a portion of pile and drilled shaft design seminars which ADOT occasionally hosts. We believe that this process provides the best chance of speeding implementation of the proposed recommendations. Once again, the precise content of this presentation will be influenced by the research itself, but should include a brief summary of the research conducted and the recommended design methods. We plan to develop at least one example problem with detailed calculations described, which could also be provided as a handout to those who attend the presentation. We understand the intent of the Solicitation to be for these presentations to be made by the principal investigator or other members of the project team, and propose to provide this service in that way. However, an electronic copy of the presentation materials could be provided to ADOT personnel, along with such speaker notes and coaching as may be needed to allow development of one or more ADOT trainers of this material.

Benefits

The proposed approach has several important benefits. First and foremost, the study is expected to deliver a recommended drilled shaft group design method for vertical loading which is consistent with any load testing data found in the literature, consistent with Arizona-specific analytical methods, and accepted by the consulting community, the ADOT TAC, and at least the local FHWA personnel. Quantification of the use of drilled shaft groups and the performance of those groups under previous design methods will allow definitive statements to be made about the suitability of past design methods and the structures which resulted.

The product of this research is only useful if designers can understand and accept the recommendations. Because the project manager is keenly aware of, and experienced with, ADOT design methodologies, and because of the influence of the Steering Committee, the results obtained will be carefully tied to practical application. Implementation will be furthered by the development of technical training materials and presentation modules, to be delivered by the project team frequently to as wide an audience as possible. Wide dissemination through publication of the results in national and international technical media will also allow an opportunity to influence national policy and the cost effectiveness of design.

Implementation

The results of this study will be developed in such a way that they can be moved rapidly into practice. In fact, rapid implementability will be one of the primary functions of the Steering Committee. Implementation of the results will be directly provided by:

- A Change Letter to the Materials Section Preliminary Engineering and Design Manual, which will be sent via mail to all subscribing firms. A design manual will also be prepared and made available via this process, with example calculations.
- Technical presentations in a number of suggested venues over the six months following the completion of the project. These presentations will be motivated specifically by implementation, and will include example calculations and significant attention to the application of the recommendations in practice. ADOT personnel can be trained to continue these presentations, if needed.
- Library documentation of the work will be available for those who desire more detailed information.
- A letter will be prepared to convey the recommendations and their reasons to AASHTO. Through this effort and publication of the research in TRB and journals, Arizona can have influence over the design recommendations in the next revision of AASHTO.

Facilities Available

Given the nature of the tasks to be performed during the execution of this project, the demands for facilities are modest and easily met. For the literature review, we have several large libraries on campus and interlibrary loan agreements that have proven quite acceptable. Numerous electronic search packages for citations and abstracts are available and in routine use. All faculty and graduate students have desktop computers and have access to hundreds more plus work-stations and mainframes, if needed. Finite element code ABAQUS has been selected for use and is available, up, and running. More than adequate space to do the work is available.

Available laboratory and testing equipment includes computer controlled shear testing units, consolidation units, and all index testing apparatus. Field testing equipment ranges from seismic velocity apparatus to drilling and sampling devices to pile loading test devices, and a large scale direct shear test apparatus. Two hydraulic loading rams are available at ASU, one small and one moderate sized. It will be necessary to construct 3 to 4 additional large hydraulic rams in the machine shops at ASU.

Staffing Plan

The principal investigator, Dr. Kenneth Walsh, will be directly responsible for the technical and overall day-to-day management of this project. He will be the primary contact for all technical matters. All correspondence on administrative matters should be referred to the ASU administrative officer, Mr. Joseph Wessels, Office of Research and Creative Activities at ASU, with copies to the PI.

The team assembled for this project includes ASU faculty (Dr. Kenneth Walsh, P.E., Dr. William Houston, P.E., and Dr. Sandra Houston, P.E.), graduate students (Cortland Perry, BS, EIT, and Abdalla Harraz, MS), Steering Committee consultants (Kenneth Ricker, P.E, of RAM, Keith Dahlen, P.E., of DMJM, Robert Turton, P.E., of HDR, Randolph Marwig, P.E., of WTI, and Dwaine Sergent, P.E., of Kleinfelder). This team was selected because of their abilities and experience with the issues raised by this project.

Dr. Kenneth D. Walsh, P.E., is an associate professor of construction at Arizona State University, and will serve as the Principal Investigator. Prior to accepting a faculty position in 1994, he was a practicing geotechnical engineer in the Phoenix area, and was involved in a number of ADOT bridge designs. As such, he is well acquainted with the use of the applicable design procedures. He served as the design engineer and field supervisor for the vertical load tests on the Salt River Viaduct, and completed his Ph.D. research on the behavior of drilled shafts in cemented soils of Arizona, which included the design and conduct of a pile load testing system for small diameter drilled shafts under vertical load. He teaches an undergraduate foundation course which includes lateral and vertical pile loading. Dr. Walsh was also the principal investigator and primary contact for ASU's participation in the ad hoc Task Force and for SPR 483.

Dr. William Houston, P.E., professor of civil engineering at ASU, will serve as a co-investigator. Dr. Houston is known widely as a developer of testing methods and systems for field and laboratory applications, and for his expertise in the special concerns of soils in arid environments. He has completed a number of consulting projects in Arizona and elsewhere involving vertical and lateral loading of drilled shaft and pile foundations, and has expertise in the analysis of soil-structure interaction problems. He has taught courses in deep foundations, field and laboratory testing, and soil-structure interaction. Dr. Houston was also a member of the ad hoc Task Force and a co-investigator on SPR 483.

Dr. Sandra Houston, P.E., professor of civil engineering and chair of the Department of Civil and Environmental Engineering at ASU, will also serve as a co-investigator. Her national and international reputation has been built on the development of soil mechanics for arid soils, with over thirty-five publications in this area. She also maintains expertise in numerical modeling and deep foundation behavior, and teaches graduate courses in deep foundation behavior and finite element and finite difference modeling in geotechnical applications.

Two graduate students have been selected for this project. One is an undergraduate until January, 2001, and then will become an MS student. The other is a Ph.D. student. Both will have an extended period of time at ASU for the completion of this work.

The Steering Committee consultants possess a total of 130 years of consulting experience, mostly in Arizona. Senior engineers in management and ownership roles are included, as are project engineers. They represent firms of national, regional, and local scales. Most were on the ad hoc Task Force, and all are generally familiar with the drilled shaft design process and with ADOT design procedures. All members are well known in local practice. Considered collectively, this group is extraordinarily well qualified to advise and guide the implementation of the results of this research into local professional practice.

Proposed Project Budget By Task

The proposed budget is summarized on the table on the next page. The budget is broken down by task as required by ADOT. The budget includes a significant component ($48,214) for the construction and conduct of the load test. This amount is not enough to cover the entire load test, obviously, but represents the contribution from this project budget toward the joint load testing for SPR 483/SPR 493. A detailed budget for the entire load test is in preparation and will be submitted under separate cover.

Proposed Budget By Task

Drilled Shaft Bridge Foundation Design Parameters and Procedures for Bearing in SGC Soils

SPR 493

Item	Task 1	Task 2	Task 3	Task 4/5	Task 6	Task 7	Task 8	Task 9	Task 10	Total
Labor										
Walsh	$409.42	$1,638	$1,638	$1,638	$3,071	$3,071	$5,118	$2,866	$1,024	$20,471
Houston, W.	$431.80	$1,727	$1,727	$1,727	$2,591	$4,318	$6,909	$1,080	$1,080	$21,590
Perry	$0.00	$3,856	$2,892	$964	$0	$5,783	$5,783	$0	$0	$19,278
Harraz	$278.46	$2,785	$1,392	$5,569	$2,785	$8,354	$3,898	$2,785	$0	$27,846
Other Costs										
Travel			$315		$630		$1,575	$630	$1,890	$3,780
Copying					$442					$1,260
Software					$95				$95	$442
Postage and Delivery										$189
Load Test Equipment and Materials							$48,214			$48,214
SUBCONTRACTORS										
Labor										
RAM	$138.60	$0	$139	$0	$554	$0	$139	$277	$139	$1,386
DMJM	$138.60	$0	$139	$0	$554	$0	$139	$277	$139	$1,386
HDR	$138.60	$0	$139	$0	$554	$0	$139	$277	$139	$1,386
Kleinfelder	$138.60	$0	$139	$0	$554	$0	$139	$277	$139	$1,386
WTI	$138.60	$0	$139	$0	$554	$0	$139	$277	$139	$1,386
TOTAL BUDGET	$1,813	$10,005	$8,657	$9,898	$12,385	$21,526	$72,190	$8,745	$4,781	$150,000

List of References Cited

AASHTO. "Standard Specifications for Highway Bridges." 16th edition 1996.

Beckwith, G.H., and Bedenkop, D.V. (1973), "An Investigation of the Load Carrying Capacity of Drilled Cast-In-Place Concrete Piles Bearing on Coarse Alluvial Fan Deposits," Arizona Highway Department Research Report No. AHD-RD-10-122.

Houston, W.N., Houston, S.L., Liu, J.W., El-Sayed, A., and Sanders, C.O. (1995), "In-situ Testing Methods for Dynamic Properties of MSW Landfills," *Proceedings*, Specialty Conference on Earthquake Design and Performance of Solid Waste Landfills, Geotechnical Specialty Publication No. 54, ASCE, New York, NY, pp. 73-82.

Kulhawy, F.H., and Jackson, C.S. (1989), "Some observations on undrained side resistance of drilled shafts," *Proceedings*, Foundation Engineering Congress: Foundation Engineering – Current Principles and Practices, New York, American Society of Civil Engineers, pp. 1011-1025.

Reese, L.C., and O'Neill, M.W. (1988), "New design method for drilled shafts from common soil and rock tests," *Proceedings*, Foundation Engineering Congress: Foundation Engineering – Current Principles and Practices, New York, American Society of Civil Engineers, pp. 1026-1039

Sharma, H.D., and Joshi, R.C. (1988), "Drilled Pile Behaviour in Granular Deposits," *Canadian Geotechnical Journal*, 25 (5), 222-232.

FM

ARIZONA DEPARTMENT OF TRANSPORTATION
PROGRESS PAYMENT REPORT

		Progress	Final	Payment Report	
Report No.	FA	Non FA	Exp. Budget Obj. Code		JPA 00-158

Project No. SPR-93 Date Ending:

TRACS No. R0493 12P

Name of Project Drilled Shaft Bridge Foundation Design and Procedures for Bearing in SCG soil

Name of Sponsor ASU, Del Webb School of Construction, PO Box 870204, Tempe, AZ 85287-0204

Date Started Estimated Completion Date: % Billed % Complete

SUMMARY OF WORK FOR WHICH PAYMENT IS REQUESTED

ITEM	DESCRIPTION	CONTRACT AMOUNT ESTIMATE	Previous Accumulative Amount	Current Month	Accumulative Amount
1	AS PER JPA 00-158	$150,000.00			

Submitted By: ______________________	Date: __________	Total: To: Date:
Approved By: ______________________ ADOT Project Manager	Date: __________	Total: Previous: Report: $0.00
Approved By: ______________________ Joint Project Administration	Date: __________	Current: Report:

CONMASTR/PRFORMAT